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Boscán Field, Western Venezuela[1]

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Abstract The Boscán field, discovered in 1946, produces from a structural-stratigraphic trap formed by a combination of faulting and the truncation and facies change of upper Eocene and lower Oligocene sandstones. It was discovered following a conventional seismic survey which detected the structural element of entrapment; the stratigraphic changes controlling the accumulation, which are known from subsurface geology, were not recognizable from geophysical data. Boscán has produced more than 350 million bbl of 10.3° API gravity oil.

Introduction

Several large accumulations of heavy oil are present on the north and northeast sides of Lake Maracaibo (Fig. 1). Boscán field is located apart from the others on the west side of the lake in flat, low-lying country about 40 km (25 mi) southwest of Maracaibo. The Perijá highway cuts through the north end of the field, providing easy access from Maracaibo.

Boscán is a structural-stratigraphic trap. The reservoir consists of basal Oligocene sandstones above and upper Eocene sandstones below an important unconformity (Figs. 2, 3). Regional dip is to the southwest, and the principal trapping mechanism is the northward truncation of the reservoir sandstones and their gradation to shale. Closure is completed on the east by the Boscán fault, which limits oil accumulation in that direction.

Boscán has produced more than 350 million bbl of oil with an average API gravity of 10.3°. Current production is approximately 60,000 bbl/day.

Discovery

Exploration of the area west of Maracaibo, which began in the early 1900s, was stimulated by knowledge of the numerous oil seeps associated with mountain-front outcrops and foothills structures on the northern Perijá. Surface geologic mapping between the mountains and the lake led to the discovery of the La Paz and Concepción structures, which were drilled by Shell and put on commercial production in 1925. These discoveries caused interest in the area downdip to the south, where lack of surface exposures forced the introduction of geophysical methods of exploration.

During the late 1920s exploration in the Boscán area consisted of magnetometer and torsion-balance surveys and drilling of structure test holes. Although no well-developed structures were defined, three exploratory wells were drilled in 1929 and 1930. Two of these established the presence of heavy oil in the upper Eocene, but neither proved commercial; as a result, the concessions on which they had been located were relinquished.

In 1944 Richmond Exploration Company (now Chevron Oil Company of Venezuela) acquired a large concession block west of Lake Maracaibo which included the Boscán area. This acreage was explored by a 1945–1946 reflection seismic survey; particular attention was given to the areas downplunge from producing structures on the north.

The split-spread continuous-profiling method was used and a 16-trace set of reflection seismograph instruments and an oscillograph were used to record the data. Shotpoints were located at 300-m (984 ft) intervals on lines forming roughly a 4 mi by 4 mi (NW-SE and NE-SW) rectangular grid. Single geophones located 33⅓ m (109 ft) apart formed the detector spread. Shotholes were drilled to depths ranging from 80 to 120 ft (25 to 35 m) and charge sizes varied from 5 to 25 lb of dynamite. This shooting and recording technique was successful in obtaining fair, correlatable reflection data from upper Eocene and post-Eocene sedimentary units, but only poor and discontinuous reflection data were obtained from the lower Eocene, Paleocene, and Cretaceous.

Reflection data obtained from this survey were interpreted and then plotted, by use of a curved-ray wavefront chart, onto migrated dip sections. Structure maps were contoured from

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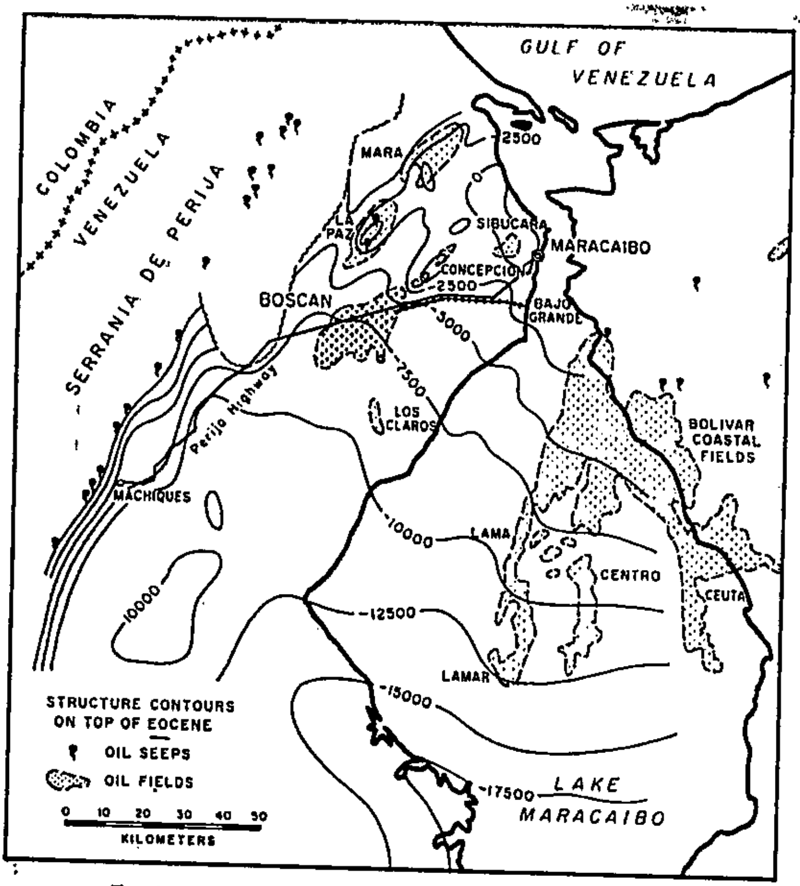


FIG. 1—Western Venezuela, showing location of Boscán field.

depth data obtained from mapping horizons drawn on the migrated sections.

One of the first areas surveyed was that which is now East Boscán, south of the Concepción field. The map (Fig. 4A) indicated a nose plunging south from Concepción with two small areas of local closure. The more southerly of the two was tested in 1946 by the Zulia 7F-1 well. This well was programmed originally as a Cretaceous test to be drilled to 13,500 ft (4,100 m), but mechanical problems forced its termination at 9,598 ft (2,925 m). However, approximately 400 ft (130 m) of oil sandstone had been penetrated in the basal Oligocene and upper Eocene. The well was plugged back to this interval and completed for an initial potential of 230 bbl/day of 10.5° API gravity oil.

Because of the belief that the heavy gravity of the oil in the 7F-1 well was due to oxidation at a fossil seep where oil had escaped through the post-Eocene unconformity, the second Boscán well, 7G-1, was located 2.5 km (1.5 mi) downdip to the south. This location was east of the Boscán fault, however, and the section productive in the 7F-1 well was water-bearing. It was not realized at that time how fortunate the choice of the first location had been. Later drilling has shown that well 7F-1 intersected the Boscán normal fault in the Oligocene, not far above the productive section, which was on the upthrown side of the fault. If it had been drilled a few hundred feet to the east, still on the structure as it then was mapped, the well would have been on the downthrown side and almost certainly would have been dry.

In 1947, two more evaluation wells were drilled. Well 7D-1 tested the other high mapped north of the discovery well (Fig. 4A), and well 10C-1 tested another small structure 12 km (7.4 mi) farther west. Both wells found heavy

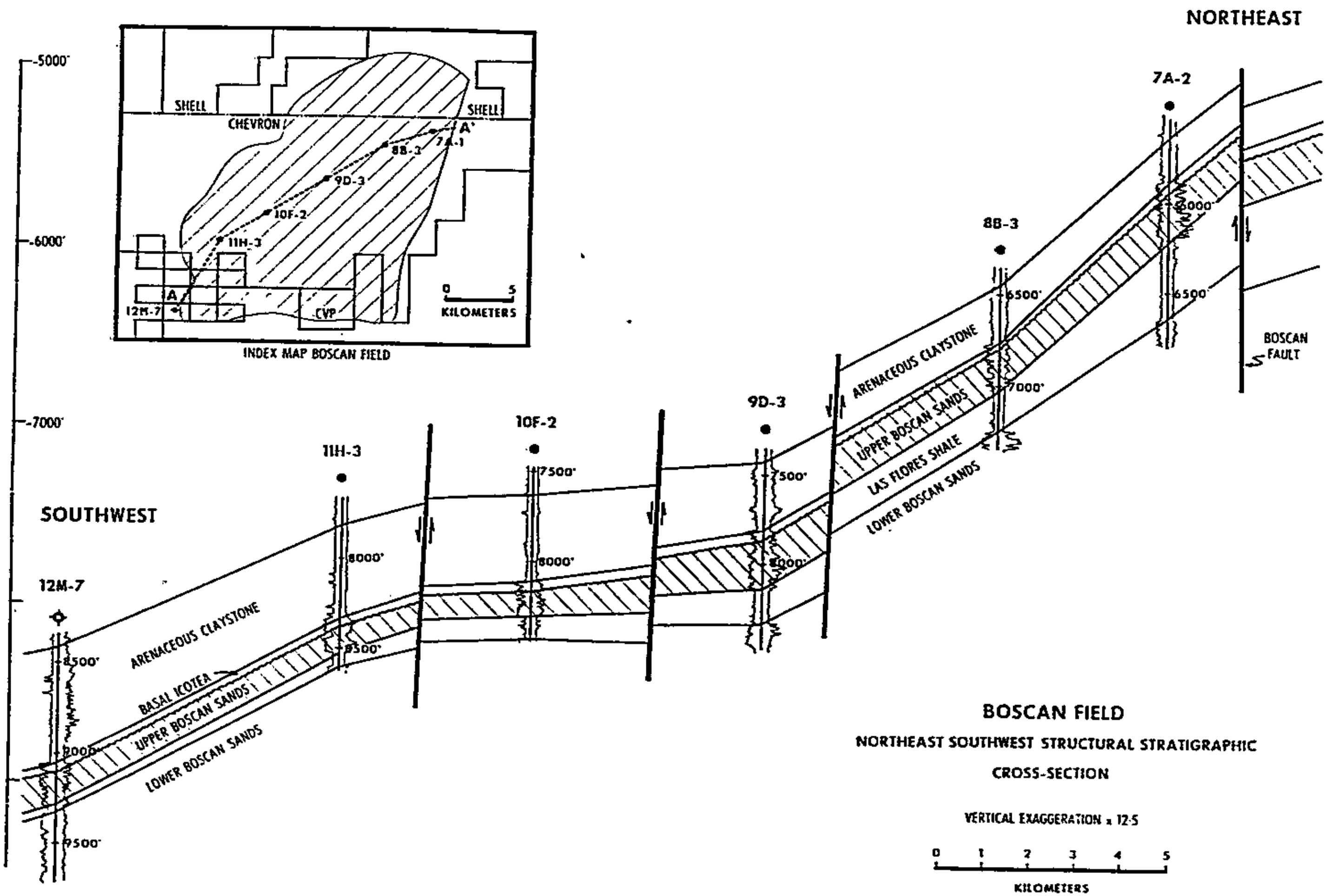


FIG. 2—Structural-stratigraphic cross-section *A-A'*.

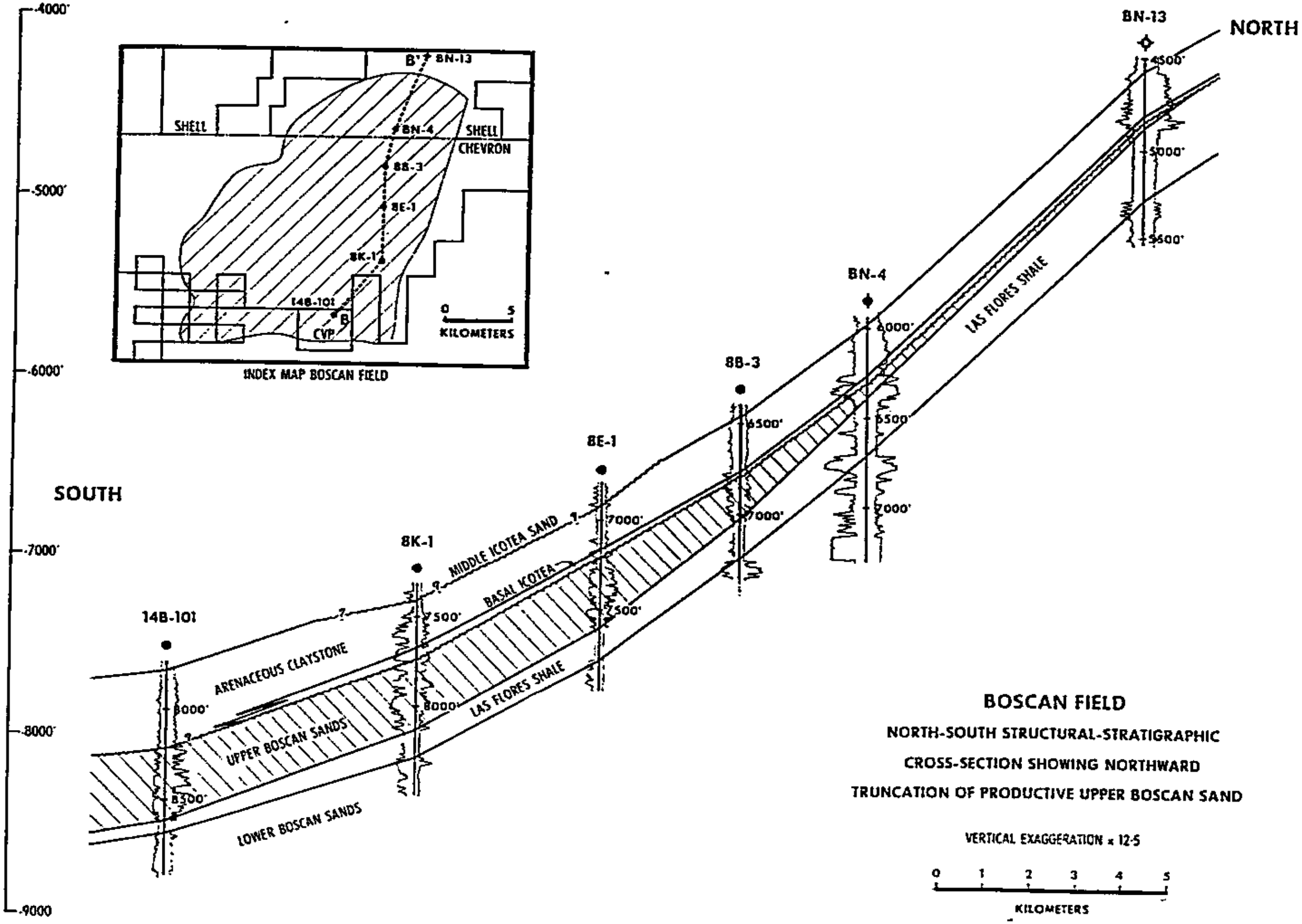


FIG. 3—Structural-stratigraphic cross-section *B-B'*.

oil similar to that from the 7F-1 well, thus giving the first indication of the possible size and importance of Boscán.

The subsequent development and production history of the field is illustrated in Figure 5. In 1951 Shell extended the field onto their concession north of the Chevron block, and in 1963 the Corporación Venezolana del Petróleo (the Venezuelan national oil company) began development of their assigned acreage on the south. Production of all three companies is transported via an 18-in. pipeline to Chevron's Bajo Grande terminal on Lake Maracaibo.

Character of Oil

Boscán crude oil has several unusual properties, including heavy gravity and high viscosity, which have forced the adoption of special handling techniques. At the well a pump with high capacity is required to lift the oil from depths of 5,000–8,500 ft (1,525–2,590 m) at rates of up to 1,000 bbl/day, and sand incursion is a problem requiring frequent clean-up jobs. Before entering the pipeline to Bajo Grande, the oil must be heated to over 200°F in order to lower the viscosity and make it pumpable; once it reaches Bajo Grande, it must be reheated and shipped only in tankers equipped with heating coils. The importance of maintaining a suitable temperature of 150–160°F on the voyage was realized early—immediately after an unheated shipment arrived in Sweden in the winter. Boscán oil has a high sulfur content of 5.5 percent and probably an unequalled vanadium content of 1,200 ppm. Fortunately, these contaminants do not detract from its value as a quality asphalt stock.

Stratigraphy

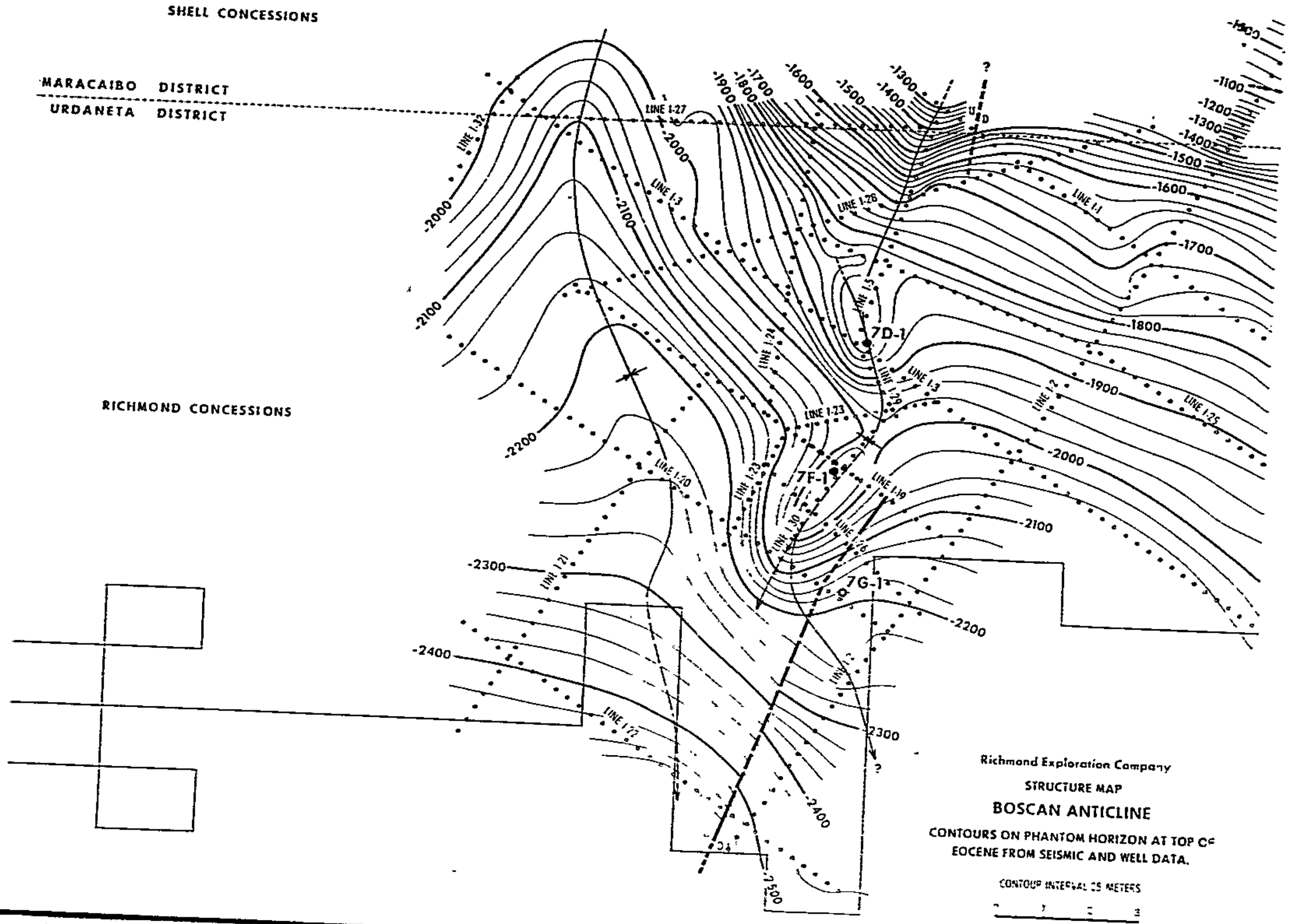
Boscán's relative isolation from the other Eocene unconformity oil fields east of Lake Maracaibo has led to the development of an informal local stratigraphic nomenclature that is still poorly tied to the rest of the Maracaibo basin.

The few Boscán wells that penetrate below the producing sandstones at the top of the Eocene show the Eocene Misoa Formation to consist of a series of interbedded, shallow-marine to brackish-water sandstones and shales, which thin abruptly westward from more than 5,000 ft (1,525 m) at the eastern edge of the field to about 1,500 ft (455 m) in the west. Most of this thinning is due to truncation at probably at least two intra-Eocene unconformities, onlap, and depositional wedgeout toward a contemporaneous high west of the field. Post-Eocene erosion is relatively unimportant in this direction, as shown on cross-section *A-A′* (Fig. 2).

The productive Eocene interval, which subcrops below the basal Oligocene, consists of two sandstone zones, the "Upper" and "Lower" Boscán, separated by the informally named "Las Flores" shale. The Boscán sandstones seem to correlate generally with the upper "B" sandstones of the Bolívar coastal fields on the east, but a lack of diagnostic microfauna precludes a more precise tie. Palynological studies suggest that the "Upper" Boscán may correlate with part of the La Sierra Formation, which outcrops in the Serranía de Perijá to the west.

North-south cross-section *B-B′* (Fig. 3) illustrates the stratigraphic changes which control Eocene oil accumulation at Boscán. The most significant element is the post-Eocene northward truncation of the "Upper" Boscán sandstones, which comprise the most widespread and important reservoir of the field. These sandstones thin from more than 400 ft (120 m) in the south to zero in the north. Although this erosion is obvious from subsurface control, it is not apparent on the few seismic lines that extend to the northern limit of the field. The reason for this is the absence in the upper Eocene of any reflector continuous enough to define intra-Eocene structure. Modern seismic methods certainly would improve this situation, but there is no incentive to reshoot the area because the field already has been defined by well control. It is very doubtful, however, that any type of seismic survey using modern shooting, recording, and processing techniques could map the other important stratigraphic change—the northward gradation to shale of the "Lower" Boscán. The Eocene basin opened northeastward from Boscán, and Eocene isopachs and shale content increase in that direction. The "Lower" Boscán sandstones, which are medium to coarse grained in the south and have good porosity and permeability, become progressively finer northward and so impermeable as to be incapable of production.

The Las Flores shale, which separates the "Upper" and "Lower" Boscán, shows great local variation in thickness. In the south and southwest parts of the field it is thin or virtually absent, but in the northeast its thickness increases to more than 400 ft (120 m). Part of this increase may be due to the gradation to shale of the "Upper" and/or "Lower" Boscán sandstone in a seaward direction, but field studies suggest it more likely is due to truncation below a local



Richmond Exploration Company

STRUCTURE MAP

BOSCAN ANTICLINE

CONTOURS ON PHANTOM HORIZON AT TOP OF EOCENE FROM SEISMIC AND WELL DATA.

CONTOUR INTERVAL 25 METERS

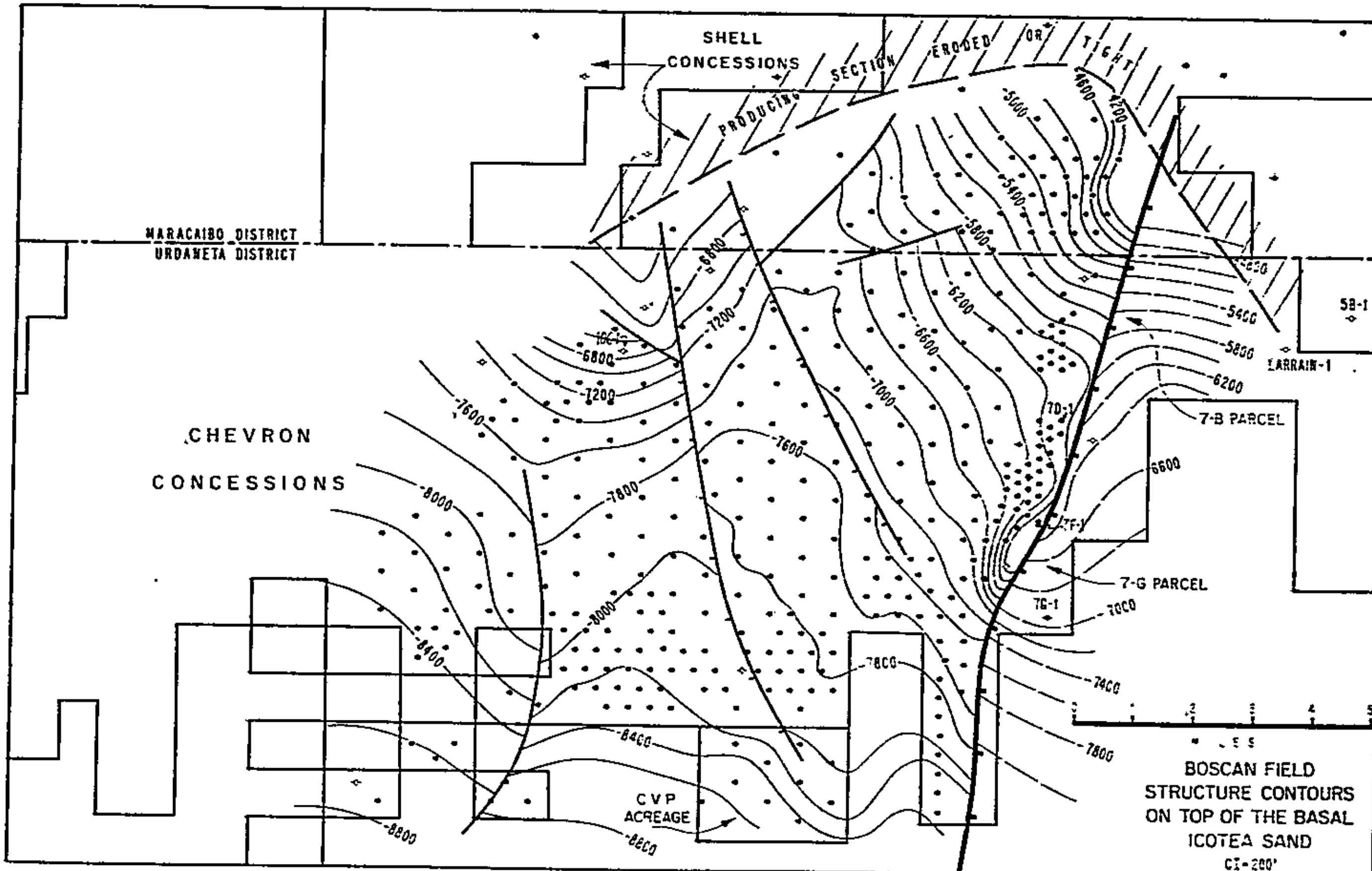


FIG. 4B—Present-day structure map of Boscán field.

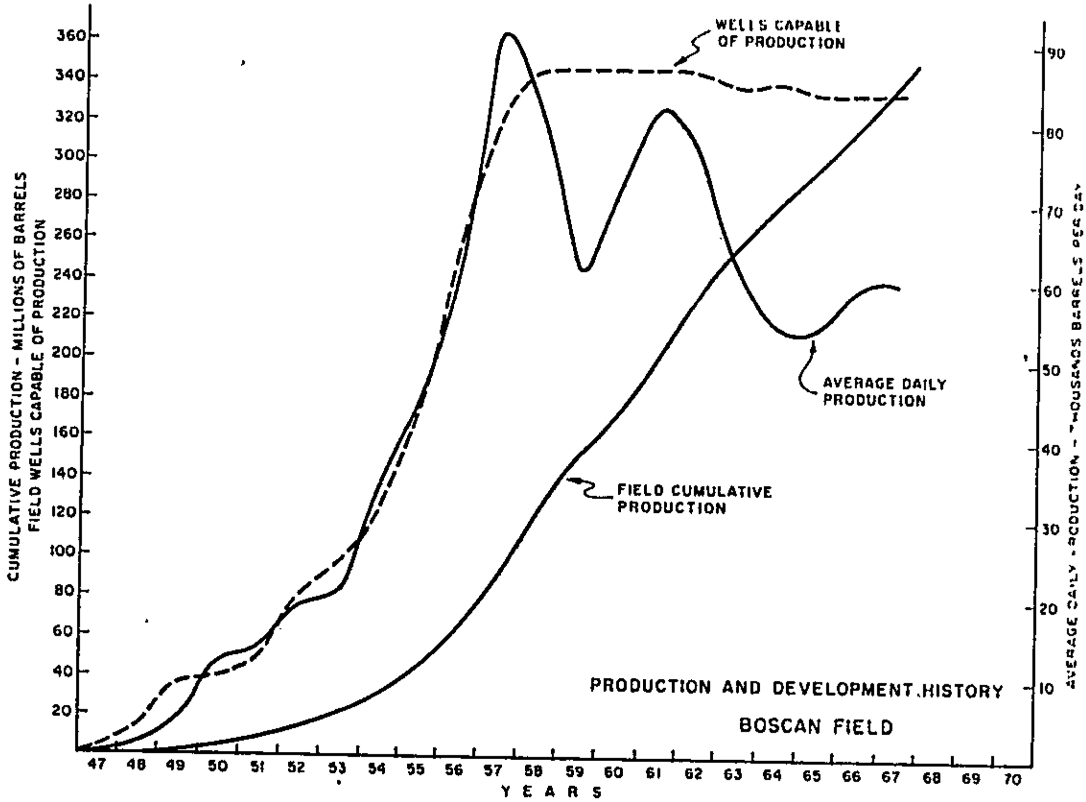


FIG. 5—Development and production history of Boscán field.

unconformity at the base of the "Upper" Boscán.

The Eocene is overlain unconformably by the Oligocene Icotea Formation. The Icotea, which is a transgressive sequence deposited after widespread uplift across the Maracaibo basin, thickens across the Boscán area from 650 ft (200 m) in the northeast to 1,650 ft (505 m) in the southwest. Economically, its most important member is the basal sandstone, which is irregularly productive across most of the field. The Icotea is much more varied in lithology than the Eocene, and, for that reason, makes a poorer reservoir. Abrupt and erratic increases in its silt and interstitial clay content lower its overall average effective porosity and, as presently correlated, eliminate it as a productive zone toward the north and south limits of the field. The correlations are not well established, however, as neither the basal Icotea nor "Upper" Boscán has a characteristic electric-log marker that can be followed from well to well; both display enough variability in sandstone development to make correlations very uncertain. In the few places where well-cored sections are available, heavy-mineral analysis can be used to differentiate the formations, but these control points are too widely scattered to be of much value. It is entirely possible that the Eocene surface was eroded more irregularly than is now believed, and some sandstones now thought to be "Upper" Boscán actually may be thickened "Basal" Icotea sections occupying paleotopographic lows.

The "Basal" Icotea sandstone is overlain by the "Arenaceous Claystone" member of the Icotea. This claystone has a characteristic lithology of white to light gray or green, kaolinitic claystone with scattered angular quartz grains; it contains thin interbeds of argillaceous siltstone. It probably was deposited in a continental environment on a low-lying coastal plain or in brackish-water lagoons. The "Middle" Icotea sandstone, which is locally developed at the top of the "Arenaceous Claystone," is the youngest producing unit in Boscán. It is a series of interbedded fine-grained sandstones and shales up to 100 ft (30 m) thick. It may represent a channel deposit contemporaneous with, or slightly younger than, the upper "Arenaceous Claystone." It produces in a limited area close to the Boscán fault.

The "Upper" Icotea consists of a series of yellow limonitic claystones with rounded inclusions of anhydrite or gypsum. This facies, which is developed all across the Boscán field, can be followed in the subsurface 40 km (25 mi) to the south but disappears abruptly to the east and north. It apparently was deposited in a shallow, inland drainage basin subject to strong evaporation.

The Icotea is overlain by the lower Miocene La Rosa shale. This unit was laid down during the maximum extent of the post-Eocene transgression; it is a shallow-marine to tidal-flat deposit, containing abundant shell fragments. It contains minor interbeds of "tight" fine-grained sandstone, but these are not productive in the Boscán area.

The La Rosa is covered by a thick regressive series of mottled brown, green, and red claystones and sandstones ranging in age from Miocene to Pleistocene. These units contain no oil shows and are of no commercial interest. This section thickens from 4,500 ft (1,370 m) in the northeast to 8,000 ft (2,450 m) in the southwest.

Structure

The structural setting of Boscán is simple compared to that of the Concepción-La Paz area to the north. At the top of the Eocene level, regional dip is to the west-southwest at approximately 25 ft/mi (5 m/km). There is no folding of any consequence and the main anomalies are introduced by north-south-trending faults.

The most important of these faults is the Boscán fault, which provides eastern closure for the field. The Boscán fault is a normal fault with varied down-to-the-east throw. Few wells have been drilled on its downthrown side, so its movement has been determined mainly on the basis of seismic mapping. A wide range of offset is indicated, apparently the result of the development of small fold anomalies on the west side which are not duplicated on the east. In the 7G land parcel, the fault shows its greatest throw of 800 ft (250 m), which decreases to less than 100 ft (30 m) in the 7B parcel 6 km (4 mi) to the north, then increases to 500 ft (155 m) north of the Shell-Chevron concession boundary.

Assuming the small throw indicated across the Boscán fault in the 7B parcel is correct, it is surprising that it has been so effective in controlling the updip migration of oil at Boscán. Two factors may explain this anomaly. First, seismic mapping has shown that the Eocene thins westward across the fault, indicating fault movement close to the time of deposition of the reservoir sands. Contemporaneous movement would have affected the topographic relief of the surface of deposition and might have caused a westward facies change to more shaly, less permeable sandstones. Alternatively, slightly later activity could have induced local squeezing and early compaction of the soft sediments along the fault plane, making them an effective permeability barrier. The other explanation might be simply that, through a fortunate coincidence, the Boscán sandstones had become shaly enough in the north end of the field that a small throw was sufficient to offset the permeable layers and form an effective trap. Though effective, it was not a 100-percent barrier, and a limited amount of oil apparently did cross; this oil probably accounts for the noncommercial shows encountered in the 1930 wildcat, Larrain-1. A follow-up to this well, 5B-1, which was drilled in 1956, found the Boscán and Icotea "tight" with very spotty saturation, suggesting that stratigraphy actually controlled Boscán entrapment both to the north and the northeast. Without the eastern closure added by the Boscán fault south of parcel 7B, however, the resulting field would be only a small fraction of its present size.

Conclusion

Boscán is an oil field that owes its existence to stratigraphic entrapment and its size to structural enlargement. It was discovered by a well drilled on a seismic anomaly; the seismic interpretation, however, did not predict the stratigraphic element of the trap. It is possible that careful time-interval analysis could have detected the northward truncation of the "Upper" Boscán prior to drilling, but it is overwhelmingly probable that, if the area were to be reexplored today, Boscán again would be discovered on the basis of its secondary structural characteristics.